

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appellant: William A. Welsh
Serial No.: 10/685,215
Filed: October 14, 2003
Group Art Unit: 3656
Examiner: Johnson, Vicky A.
Title: ACTIVE FORCE GENERATION SYSTEM FOR MINIMIZING
VIBRATION IN A ROTATING SYSTEM

APPEAL BRIEF

Subsequent to the filing of the Notice of Appeal on 11 October 2011 Appellant hereby submits its brief.

I. Real Party in Interest

Sikorsky Aircraft Corporation is the real party in interest of the present application. See reel/frame: 014614/0487.

II. Related Appeals and Interferences

This application was previously appealed. See Appeal No. 2009-002774. A copy of the decision is included in the Appendix as **Exhibit A**.

III. Status of the Claims

Claims 11-36 are pending, however only claims 22, 25-27, and 29-36 are rejected.

Claims 11-21, 23-24 and 28 stand withdrawn, and claims 1-10 stand cancelled.

IV. Status of Amendments

All amendments have been entered.

V. Summary of Claimed Subject Matter

Disclosed is vibration isolation system 10 for reducing vibrations generated by a rotating system 2. The rotating system 2 can produce certain vibrations during operation. When left unattenuated or unabated, these vibrations may lead to structural fatigue and premature failure of system components.

In one example, a multiple of masses M1, M2 are coaxially disposed about an axis of rotation 6 of a rotating system 2, and a drive system 30 spins masses M1, M2 about the axis of rotation 6, as controlled by a control system 40. See Appellant's Figure 4, below. These masses can be spun independently, which provides for an increased level of control over the vibration isolation force magnitude and phase.

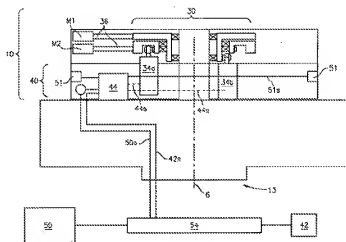


FIG. 4

Summary of independent claim 22

Claim 22 generally relates to a vibration isolation system 10 for reducing vibrations in a rotating system 2 rotatable about an axis of rotation 6. A multiple of masses M1, M2 are coaxially disposed about an axis of rotation 6 of a rotating system 2, and each of the multiple of masses M1, M2 are radially offset from the axis of rotation 6. A drive system 30 independently spins each of the masses M1, M2 about the axis of rotation 6 at an angular velocity. Further, a control system 40 is in communication with the drive system 30 to control the angular velocity of each of the multiple of masses M1, M2 to reduce vibrations generated by the rotating system 2. (See page 7, ll. 5-25).

VI. Grounds of Rejection to be Reviewed on Appeal

Claims 22, 25-27 and 29-36 stand rejected (see the Final of 22 June 2011) under § 103(a) as being obvious over Ueda (JP 61164109) in view of Perry (U.S. Patent No. 6,813,973).

Note that the Ueda reference is originally in Japanese. A translation of Ueda was made available earlier in prosecution, and is attached hereto as **Exhibit B** for convenience.

VII. Argument

A. Dependent claims 25-27 and 29-36 have not been properly addressed

While listed in the grounds of rejection, the Examiner has not actually addressed these dependent claims. Instead, the Examiner has only proffered a substantive rejection of independent claim 22.

As the Board is well aware, the Examiner has the burden of producing a prima facie case of obviousness. (See MPEP § 2142, noting that “[t]he examiner bears the initial burden of factually supporting any prima facie conclusion of obviousness”). Further, as explained by the Supreme Court in the KSR case, the key to supporting a prima facie case of obviousness “is the clear articulation of the reason(s) why the claimed invention would have been obvious.” (MPEP § 2142).

Here, the Examiner has not provided any explanation of the manner in which the dependent claims are being rejected. Accordingly, there is no prima facie case of obviousness, and the rejection of these claims should be reversed.

The scope of the dependent claims does indeed extend beyond the teachings of the Ueda and Perry references, as explained in detail below. Again, it was improper for the Examiner to group these claims together without actually addressing each of the features in the dependent claims.

B. Independent claim 22 is non-obvious

Setting the dependent claims aside for a moment, independent claim 22 is non-obvious for at least the following reasons.

1. The rejection

Since the last appeal, Appellant has amended the claims to recite, among other things, that the multiple of masses are “*radially offset from said axis of rotation.*” The Examiner has admitted that Ueda lacks this feature, and turns to Perry to teach it.

The Examiner primarily relies on the Figure 6 embodiment of Ueda in her rejection, copied below.

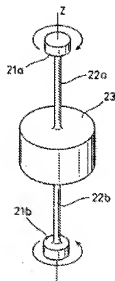


Figure 6 of the Ueda reference includes a vibrator 20, which is part of an angular velocity meter. The vibrator 20 is made of a continuous *elastic* material, and includes a case 23 and two masses 21a, 21b that “*wobble*” about the axis Z. (Ueda translation at pages 4-5, specifically noting that “[a] constantly elastic member is used as the material of vibrator 20”). When the vibrator is excited (e.g., by some outside force), the mass members 21a, 21b *react* to that excitement by wobbling back-and-forth, as permitted by the *elastic* supporting members 22a, 22b. (Ueda translation at page 4, ll. 20-30, explaining that the support section “*elastically*” supports the masses). The wobbling frequency of the mass members 21a, 21b is detected, via the detecting electrodes 35a, 35b, and is used to determine an angular velocity measurement. (Ueda translation at page 6, ll. 1-10).

The Examiner turns to Perry, which is a drive shaft that includes masses that actually do “spin” (as opposed to wobbling, like Ueda) about an axis. The Perry masses are not biased by any elastic member, as the Ueda masses are. The Examiner has stated that she is not relying on Perry for the teaching of “spinning,” but is instead including Perry only to teach “a radial arm (50, 39) radially offset from the axis of rotation.” (Final at pages 3-4).

Whereas Ueda’s masses 21a, 21b wobble, and are centered about a wobbling-axis, the Examiner apparently argues that her combination would result in Ueda’s masses being spaced from their axis, *while still continuing the disclosed wobbling motion*.

2. *The Examiner’s modification lacks a drive system to “independently spin” the masses*

As explained above, claim 22 recites “a drive system to *independently* spin each of said multiple of masses about said axis of rotation.” That is, the drive system actively, and independently, drives masses about an axis.

In Ueda, the masses M1, M2 are not independently driven about the Z axis, as claimed and disclosed. For example, once Ueda’s vibrator 20 is excited, the masses 21a, 21b wobble back and forth (essentially, in torsion) relative to the case 23. Whereas Appellant’s drive system *actively* drives each of its masses, the wobbling of Ueda’s masses is merely a *reaction* to an earlier excitement.

To support its position that Ueda discloses masses that “independently” spin, the Board pointed to the “direction arrows” in Ueda’s Figure 6. (Decision at page 4). The Board further noted that “Appellant does not address the two arrows depicted in that figure which indicate that the masses rotate in opposite directions.” (Decision at page 5).

With respect, the wobbling of Ueda’s masses 21a, 21b, although in opposing directions, is *dependent* on (and is a reaction to) the earlier excitation of the vibrator.

Considering this, and further considering that Ueda’s masses 21a, 21b are connected together as parts of a continuous, elastic body, it cannot reasonably be said that Ueda’s drive system independently spins its masses. Accordingly, claim 22 is non-obvious, and the rejection should be withdrawn.

3. Ueda's masses still do not "spin," as claimed

Even if Ueda could be said to independently drive its masses, Ueda would still not "spin" those masses, as claimed.

As mentioned above, claim 22 recites "a multiple of masses" and "a drive system to independently *spin* each of said multiple of masses about said axis of rotation at an angular velocity." In other words, the masses M1, M2 "spin," or rotate, about the axis 6 of the rotation system 2 independent of one another.

Ueda's masses do not "spin," as claimed and disclosed, but instead "wobble" relative to the Z axis, due in part to the *elasticity* of the support members 22a, 22b. Interpreting a back-and-forth wobbling motion as "spinning" is improper, and is unreasonable. Accordingly, there is no prima facie case of obviousness, and the rejection should be reversed.

While Appellant understands that Examiners are to give claim terms a broad interpretation, that interpretation must also be "consistent with the specification," and otherwise consistent with the way the terms are ordinarily used in the art. (See MPEP § 2111).

Here, the Examiner has even provided a definition of the term "spin." The Examiner interprets "spin" as "to revolve or rotate rapidly, as the earth or a top." (Final at page 3).

While the Examiner has cited an appropriate definition for the term "spin," Ueda's "wobbling" does not fit this definition. For example, and following along with the Examiner's definition, *the earth does not wobble back-and-forth about its axis*, nor would one say that a top wobbles back-and-forth. One of ordinary skill would not otherwise reasonably consider "wobbling" to be "spinning," especially considering Appellant's specification, which details the manner in which the masses M1, M2 spin about the axis 2.

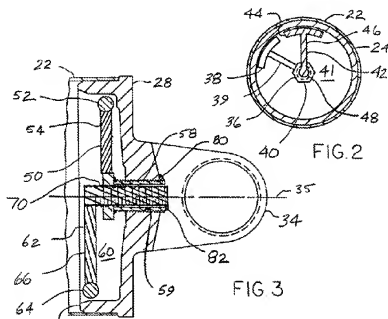
In the prior appeal, the Board's position was that "Ueda's mass members rotate, or orbit, in opposite directions around the Z-axis." (Decision at page 5).

With respect, Ueda only uses the term "orbit" when referencing element M in the schematic of Figure 5. Because Ueda's masses 21a, 21b in Figure 6 wobble in opposite directions relative to one another, and because Ueda includes *elastic* supports 22a, 22b to fix its masses 21a, 21b together, the masses cannot "orbit" their axis in opposite directions. *If they did, the elastic supports 22a, 22b would break.* Instead, the elastic supports would urge the masses back toward a relaxed position, rendering an orbit—let alone an "independent" orbit—impossible. Again, the rejection should be reversed.

4. *The suggested modification would, at a minimum, change Ueda's principle of operation*

Even outside of the above points, the combination of Ueda with Perry would impermissibly change the Ueda reference's principle of operation.

While Ueda's masses 21a, 21b wobble about their axis and are rotationally urged by the elastic supports 22a, 22b, as explained above, Perry's masses 38, 44 and 52, 64 are configured to freely spin around their axis 35, without interference from any elastic support. See Perry's Figs. 2-3, copied below:



If Ueda's masses were configured to spin—instead of wobble—then Ueda would need to be completely reconfigured. For one thing, Ueda's elastic supports would have to be done away with altogether. Additionally, Ueda relies on the detection of wobbling frequency when determining angular velocity, as noted above. Rendering Ueda's masses incapable of wobbling would, at a minimum, require a change in Ueda's basic principle of operation, if not render Ueda altogether inoperative. Such a modification is improper. (See MPEP § 2143.01). The rejection should be reversed for this additional reason.

While the Examiner has essentially taken the position that Ueda's masses would be left to wobble after being combined with Perry, and that Ueda's modified masses would not spin as Perry's do, this interpretation runs afoul of the examining guideline that "[a] prior art reference must be considered in its entirety, i.e., as a whole, including portions that would lead away from

the claimed invention.” (MPEP § 2141.02). Here, the Examiner has improperly ignored the fact that Perry’s masses *spin* about its axis, without interruption from an elastic support, when making her combination. The rejection should, again, be reversed.

5. *Ueda is not concerned with reducing the vibrations in its system*

Claim 22 recites “a control system in communication with said drive system to control the angular velocity of each of said multiple of *masses to reduce vibrations generated by the rotating system*.” (emphasis added). In Ueda, there is simply no control system that reduces vibrations. Instead, Ueda’s system *measures vibrations*, or wobbling, and uses measured wobbling frequencies, resulting from those vibrations, in determining angular velocity. If Ueda reduced its vibrations, then it would not provide an accurate angular velocity measurement. Again, the rejection should be reversed.

While this feature is perhaps recited functionally, it must still be addressed. (See MPEP § 2173.05(g), which notes that “[a] functional limitation must be evaluated and considered, just like any other limitation of the claim, for what it fairly conveys to a person of ordinary skill in the pertinent art in the context in which it is used”).

C. Dependent claims 30-31 and 33-34 are non-obvious

As noted above, the Examiner has not put forth a prima facie case of obviousness regarding these dependent claims. Thus, Appellant has no duty to produce any evidence of non-obviousness. No less, these claims cannot be accounted for by a combination of the Ueda and Perry references, and should be allowed for the below reasons.

1. *Claims 30-31 and 34*

Claim 30 includes “a multiple of electric motors,” each of which spins one of the masses. Claim 31 similarly includes that each of the motors “are independently operated to independently spin” the masses, and claim 34 includes that the “drive system spins each of said multiple of masses about said axis of rotation at an independent angular velocity.”

Ueda does not include *multiple motors* configured to drive its masses independently, as claimed. Further, Ueda does not teach any system that is configured to *spin* its masses, as noted

above. Instead, Ueda measures a wobbling frequency, and bases an angular velocity calculation on that measurement.

If anything, Ueda teaches exciting its entire vibrator as a unit, and then measuring the wobbling frequencies of the masses 21a, 21b, which are located at its axial ends. (See page 11, lines 20-30). Ueda does not—and would not need to—independently drive its masses in the manner claimed in these dependent claims. These claims should be allowed.

2. *Claim 33*

Claim 33 recites that the masses are “located only on one side of said rotating system.” For example, see Appellant’s Figure 4. Ueda’s axis runs directly through the center of its masses 21a, 21b. Arranging Ueda’s masses such that they would be only on one side of its axis would significantly change the way the masses wobble—if Ueda would even wobble at all at that point. This would undoubtedly throw-off Ueda’s angular velocity calculation. Accordingly, claim 33 is non-obvious and should be allowed.

VIII. Conclusion

Based on the foregoing, the Examiner’s decision to reject the claims should be reversed.

Respectfully Submitted,

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Dated: 30 January 2012

IX. Appendix of Claims

22. A vibration isolation system for reducing vibrations in a rotating system rotatable about an axis of rotation, comprising:

a multiple of masses coaxially disposed about an axis of rotation of a rotating system, each of said multiple of masses radially offset from said axis of rotation;

a drive system to independently spin each of said multiple of masses about said axis of rotation at an angular velocity; and

a control system in communication with said drive system to control the angular velocity of each of said multiple of masses to reduce vibrations generated by the rotating system.

25. The system as recited in claim 22, wherein said drive system spins at least one of said multiple of masses in a direction opposite to the direction of rotation of said rotating system.

26. The system as recited in claim 22, wherein said drive system spins at least one of said multiple of masses at an angular velocity greater than an angular velocity of said rotating system.

27. The system as recited in claim 22, wherein said control system utilizes a phase angle from a power source as a phase angle reference to said control system.

28. The system as recited in claim 22, wherein said rotating system includes a rotary wing aircraft main rotor system.

29. The system as recited in claim 22, wherein each of said multiple of masses are mounted to an end of a radial arm.

30. The system as recited in claim 29, wherein said drive system includes a multiple of electric motors, each of said multiple of electric motors spin one of said multiple of masses through said radial arm.

31. The system as recited in claim 30, wherein each of said multiple of electric motors are independently operated to independently spin each of said multiple of masses at an independent angular velocity.
32. The system as recited in claim 22, wherein each of said multiple of masses define an eccentric mass relative to said axis of rotation.
33. The system as recited in claim 22, wherein said multiple of masses are located only on one side of said rotating system.
34. The system as recited in claim 22, wherein said drive system spins each of said multiple of masses about said axis of rotation at an independent angular velocity.
35. The system as recited in claim 32, wherein each of said multiple of masses are mounted to an end of a radial arm.
36. The system as recited in claim 22, wherein said rotating system rotates at a rotational speed of 1P and generates NP vibrations.

X. Evidence Appendix

Exhibit A—Decision in Appeal No. 2009-002774

Exhibit B—Ueda reference translation

XI. Related Proceedings Appendix

See Appeal No. 2009-002774, in which the Board issued a decision on 30 July 2009.

ATTACHMENT A



UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10685,215 ✓	10/14/2003 ✓	William A. Welsh	67008-156PUS1/5691	4100
36096 7590 07/30/2009 CARLSON, GASKEY & OLDS, P.C. 400 WEST MAPLE ROAD SUITE 350 BIRMINGHAM, MI 48009				
EXAMINER				
JOHNSON, VICKY A				
ART UNIT		PAPER NUMBER		
3656				
MAIL DATE		DELIVERY MODE		
07/30/2009		PAPER		

Please find below and/or attached an Office communication concerning this application or proceeding.


The time period for reply, if any, is set in the attached communication.

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE BOARD OF PATENT APPEALS
AND INTERFERENCES

Ex parte WILLIAM A. WELSH

Appeal 2009-002774
Application 10/685,215
Technology Center 3600

Decided:¹ July 30, 2009 

Before LINDA E. HORNER, STEFAN STAICOVICI, and
KEN B. BARRETT, *Administrative Patent Judges*.

BARRETT, *Administrative Patent Judge*.

DECISION ON APPEAL

¹ The two-month time period for filing an appeal or commencing a civil action, as recited in 37 C.F.R. § 1.304, begins to run from the decided date shown on this page of the decision. The time period does not run from the Mail Date (paper delivery) or Notification Date (electronic delivery).

STATEMENT OF THE CASE

William A. Welsh (Appellant) seeks our review under 35 U.S.C. § 134 of the final rejection of claims 22 and 25-27. We have jurisdiction under 35 U.S.C. § 6(b).

SUMMARY OF THE DECISION

We AFFIRM.

THE INVENTION

Appellant's claimed invention pertains to a system for minimizing in-plane vibration produced in a rotating system of a rotary-wing aircraft. (Subst. Spec. 1, ll. 3-5.) Claim 22, reproduced below, is representative of the subject matter on appeal.

22. A vibration isolation system for reducing vibrations in a rotating system rotatable about an axis of rotation, comprising:

a multiple of independently rotatable masses coaxially disposed about an axis of rotation of a rotating system;

a drive system interconnected to each of said multiple of independently rotatable masses to independently rotate each of said multiple of independently rotatable masses about said axis of rotation; and

a control system in communication with said drive system to control an angular velocity of at least one of said multiple of independently rotatable masses to reduce in-plane vibration of the rotating system.

THE REJECTION

The Examiner relies upon the following as evidence of unpatentability:

Ueda et al. (as translated) JP 61-164109 Published July 24, 1986

Before us for review is the Examiner's rejection of claims 22 and 25-27 under 35 U.S.C. § 102(b) as anticipated by Ueda.

ISSUE

The Examiner found that Ueda discloses all of the limitations of Appellant's claim 22. (Ans. 3-4.) Appellant argues that Ueda's elements 21a and 21b cannot be considered to be independently rotatable masses. (App. Br. 6-7.) Therefore, the issue on appeal is:

Has Appellant shown that the Examiner erred in finding that Ueda discloses independently rotatable masses?

FINDINGS OF FACT

We find that the following enumerated findings are supported by at least a preponderance of the evidence.

1. Ueda discloses a vibration type angular velocity meter using multiple vibrators, each comprising a wobbling mass member and a supporting section.

(Ueda 2.) Figure 6 of Ueda is reproduced below:

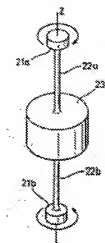


Figure 6 depicts an embodiment having two vibrator units. (*Id.* at 12.)

2. The device shown in Ueda's Figure 6 has two wobbling mass members 21a and 21b elastically supported on case 23 by supporting sections 22a and 22b, respectively. (Ueda 5, 12.) As indicated by the direction arrows depicted in Figure 6, the mass members rotate in opposite directions. (*Id.* at 5, 12, fig. 6.) The wobbling mass members move in an orbit around the Z-axis. (*See id.* at 8, fig. 3.) The device contains an excitation means for wobbling the mass members. (*Id.* at 5.)

3. Ueda's device is utilized for obtaining an attitude control signal for an aircraft. (Ueda 2.) The device contains an arithmetic operation part that computes the difference between the frequencies of the vibrators so as to compute their angular velocities. (*Id.* at 5.)

PRINCIPLES OF LAW

"A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros., Inc. v. Union Oil Co. of Cal.*, 814 F.2d 628, 631 (Fed. Cir. 1987) (citations omitted).

ANALYSIS

Appellant argues the rejected claims as a group. (App. Br. 3-7.) We select claim 22 as the representative claim, and claims 25-27 stand or fall with claim 22. 37 C.F.R. § 41.37(c)(1)(vii) (2009).

Claim 22 recites "a multiple of independently rotatable masses." Appellant disputes the Examiner's finding that Ueda's elements 21a and 21b correspond to the recited independently rotatable masses. (App. Br. 6-7.) Specifically, Appellant contends that Ueda's Figure 6 illustrates a solid interface between the different components, and therefore does not show any structure which provides for rotation. (*Id.* at 6.) However, Appellant's observation merely suggests that Ueda's mass members do not spin on the Z-axis. Appellant does not address the two arrows depicted in that figure which indicate that the masses rotate in opposite directions. As set forth in our findings above, Ueda's mass members rotate, or orbit, in opposite directions around the Z-axis. (Facts 1, 2.) Accordingly, Appellant has not persuaded us that the Examiner erred in finding that Ueda discloses independently rotatable masses as recited in claim 22. Appellant does not offer persuasive argument or evidence that any other claim limitation is missing from the Ueda disclosure.

Appellant asserts that, because the Examiner relies on the Ueda patent and a translation of Ueda was not received until receipt of the Answer, “the record is simply not clear as to the precise facts the Examiner is relying upon in support of the rejection.” (Reply Br. 2.) Appellant, however, does not point to any specific aspect of the rejection that remains unclear after receipt of the translation along with the Examiner’s Answer containing an explanation of the rejection. Appellant’s mere assertion that the “precise facts” are not clear does not identify with particularity any error in the rejection. Further, to the extent that Appellant argues that the rejection should be reversed due to purported procedural missteps, we note that procedural matters do not fall within our jurisdiction. *See In re Mindick*, 371 F.2d 892, 894 (CCPA 1967).

We sustain the rejection of claim 22, as well as the rejection of claims 25-27 which fall with claim 22.

CONCLUSIONS

Appellant has not shown that the Examiner erred in finding that Ueda discloses independently rotatable masses.

DECISION

The decision of the Examiner to reject claims 22 and 25-27 is affirmed.

No time period for taking any subsequent action in connection with this appeal may be extended under 37 C.F.R. § 1.136(a). *See* 37 C.F.R. § 1.136(a)(1)(iv) (2007).

AFFIRMED

Appeal 2009-002774
Application 10/685,215

Klh

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ATTACHMENT B

PTO 07-6692

CC = JP
19860724
Kokai
61164109

VIBRATION TYPE ANGULAR VELOCITY METER
[Shindo-shiki kaku-sokudokei]

Toshitsugu Ueda et al.

UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. SEPTEMBER 2007
TRANSLATED BY: THE MCELROY TRANSLATION COMPANY

PUBLICATION COUNTRY	(10):	JP
DOCUMENT NUMBER	(11):	61164109
DOCUMENT KIND	(12):	Kokai
PUBLICATION DATE	(43):	19860724
APPLICATION NUMBER	(21):	60005592
APPLICATION DATE	(22):	19850116
INTERNATIONAL CLASSIFICATION ⁴	(51):	G 01 C 19/56 G 01 P 9/02
INVENTORS	(72):	Toshitsugu Ueda et al.
APPLICANT	(71):	Yokokawa Hokushin Electric Corp.
TITLE	(54):	VIBRATION TYPE ANGULAR VELOCITY METER
FOREIGN TITLE	[54A]:	Shindo-shiki kaku-sokudokei

Claims

1. A vibration type angular velocity meter characterized by comprising a vibrator equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting section of the aforementioned vibrator, an excitation means for wobbling the aforementioned mass member of the aforementioned vibrator, a frequency detection means for detecting the frequency of the aforementioned wobbling, a self-excitation circuit for wobbling the aforementioned vibrator, and an arithmetic part for computing an angular velocity of the aforementioned vibrator in accordance with a change in the frequency of the aforementioned vibrator.

2. A vibration type angular velocity meter characterized by comprising multiple vibrators [each] equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting sections of the aforementioned vibrators, an excitation means for wobbling at least one of the aforementioned vibrators while wobbling the other vibrator in the opposite direction or vibrating it in a bending fashion in a linear direction, a self-excitation circuit for wobbling the aforementioned vibrators, and an arithmetic part that computes the difference between the frequencies of the aforementioned vibrators so as to compute the levels and the directions of the angular velocities of the aforementioned vibrators.

Detailed explanation of the invention

Industrial application field

The present invention pertains to a vibration type angular velocity meter utilized for obtaining an attitude control signal for such a moving body as an aircraft.

Conventional example

A vibration type angular velocity meter utilizing Coriolis forces is often formed into the shape of a tuning-fork because a high level can be attained for Ω so as to reduce the driving energy, and a high level of sensitivity can be achieved.

Figure 8 shows the structure of a tuning-fork-shaped vibration type angular velocity meter known through Japanese Kokai Patent Application No. Sho 35[1960]-3692 gazette, for example. 1a and 1b represent forks facing input axis Z of angular velocity Ω ; and 2a and 2b represent piezoelectric elements pressure-welded to said forks, whereby they are excited using an external AC driving power supply in order to vibrate forks 1a and 1b closer to or away from axis Z in the directions indicated by ω , that is, to generate in-plane vibrations.

Frequency of said vibrations resonates with the characteristic frequencies of forks 1a and 1b, and a large amplitude is generated using a small driving energy. /2'

When angular velocity Ω is input to axis Z, a Coriolis force, that is, a torsional torque, with the same frequency as the driving frequency and an amplitude proportional to Ω is generated in the direction orthogonal to the directions indicated by ω as indicated by A and B or A' and B'. 3 represents a shaft used to detect said torque, wherein it is connected to the bottom of the tuning-fork at one end via vibration-absorbing member 4 while fixed to base member 5 at the other end. 3a represents a torque transfer lever that is used to apply a vibrating torsional torque to piezoelectric element 6 pressure-welded to pole 5a provided on the base member and take the resulting converted electric signal to the outside.

Here, characteristic frequency of the part that includes shaft 3 and base member 5 while in a primary mode is selected in such a manner that it becomes equal to the characteristic frequency of the aforementioned in-plane vibrations of the tuning-fork while in the primary mode, and the vibrations

created by the weak Coriolis force are amplified by means of resonance before they are taken to the outside.

Problems to be solved by the invention

However, as described above, when the characteristic frequency at the driving part and the characteristic frequency at the detection part are the same, vibrations of the driving part affect the detection part, and detection of the torque generated by the weak Coriolis force becomes difficult. Thus, absorber 4 that absorbs the vibration energy on the driving side becomes essential, so that the overall structure becomes complicated.

In addition, because a piezoelectric element was used to detect the weak Coriolis force, there were problems in terms of fluctuations in the stability and the sensitivity at the zero position.

The present invention was made in the light of the aforementioned problems of the conventional technology, and its purpose is to realize a compact high-precision angular velocity meter through the utilization of a novel configuration for detecting the angular velocity based on changes in the characteristic frequency.

Means to solve the problems

In order to solve the aforementioned problems, the first invention comprises a vibrator equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting section of the aforementioned vibrator, an excitation means for wobbling the aforementioned mass member of the aforementioned vibrator, a frequency detection means for detecting the frequency of the aforementioned wobbling, a self-excitation circuit for wobbling the

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aforementioned vibrator, and an arithmetic operation part for computing an angular velocity of the aforementioned vibrator in accordance with a change in the frequency of the aforementioned vibrator.

In order to solve the aforementioned problems, the second invention comprises multiple vibrators [each] equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting sections of the aforementioned vibrators, an excitation means for wobbling at least one of the aforementioned vibrators while wobbling the other vibrator in the opposite direction or vibrating it in a bending fashion in a linear direction, a self-excitation circuit for wobbling the aforementioned vibrators, and an arithmetic operation part that computes the difference between the frequencies of the aforementioned vibrators so as to compute the levels and the directions of the angular velocities of the aforementioned vibrators.

Application examples

The first invention will be explained below using figures.

Figure 1 are perspective views showing the configuration of the cardinal part of an application example of the present invention; wherein, (a) shows a single body of vibrator, and (b) shows a partially cut-off overall view except for an arithmetic operation part.

Vibrator 20 is configured with wobbling mass member 21 and supporting section 22 that supports mass member 21, and it is equipped with case 23 for securing vibrator 20. A constantly elastic member is used as the material of vibrator 20 in order to reduce temperature-dependency of the characteristic bending frequency of the vibrator. Mass member 21 is cylindrical, supporting section 22 is in the shape of a rod with a round cross section, and they constitute a cantilever beam. Primary characteristic bending frequency ω_0 of the cantilever beam is given as

$$\omega_0 \approx \left(\frac{1.875^2}{L} \right) \sqrt{\frac{E I}{\gamma A}} \quad (21)$$

Here, l represents length of supporting section 22, I represents geometric moment of inertia of the beam, A represents cross-sectional area of the beam, g represents gravitational acceleration, γ represents weight of the beam material per a unit volume, and E represents longitudinal elastic modulus of the beam material. Mass member 21 reduces characteristic bending frequency ω_0 of vibrator 20. When characteristic bending frequency ω_0 is low, the frequency of the wobbling of vibrator 20 becomes lower, which is advantageous when detecting changes in the wobbling frequency attributable to the angular velocity.

Characteristic bending vibration modes of said vibrator come in 2 independent modes; namely, direction of line segment B-B* for characteristic vibrations at a low frequency and direction of line segment C-C* for characteristic vibrations at a high frequency. However, the vibration type angular velocity meter is used in such a manner that the characteristic frequencies of said 2 modes are adjusted to match with each other. /3

Through hole is created at the center of electrode support 31, and a mass member is placed inside of said through hole with a small gap. Electrode support 31 is usually configured using an insulation material, such as glass or ceramics; and electrodes 34a, 34b, 35a, and 35b are formed on it by means of sputtering and plating. Spacer 32 is placed between case 23 and electrode support 31, and it is used to adjust the position of counter surface 33 that faces mass member 21 placed in the through hole of the electrode support. Although 4 electrodes are formed on electrode support 31, detection electrode 35b is not shown in Figure 1 (b). As for the electrodes, 2 driving electrodes 34a and 34b and 2 detection electrodes 35a and 35b are formed in said order, and they are configured in such a manner that the 2 characteristic modes of vibrator 20 can be detected. The 4 electrodes are shaped so as to connect counter surface 33, that faces mass member 21, with terminals that are provided on outer cylindrical surface 36 for connecting with an excitation circuit and a detection circuit not shown. Said terminals are configured with the inclusion of hermetic terminals.

Figure 2 is a block diagram showing configurations of an excitation means and a frequency detection means. A self-excitation circuit is configured using the frequency detection means and a vibrator.

Detection electrodes 35a and 35b and mass member 21 constitute a capacitance. Here, vibrations of mass member 21 are taken out by capacitance detection circuit 36 in the form of changes in the capacitance. Said capacitance detection circuit 36 is configured with the inclusion of a bridge circuit, for example. Filter 37 extracts only the frequency that is equivalent to the primary characteristic bending frequency of vibrator 20 out of a signal from capacitance detection circuit 36. Phase shifter 38 decides the difference between the phase of the vibrations of mass 21 and that of automatic gain control amplification circuit (will be referred to as AGC circuit, hereinafter) 39 to be supplied to driving electrode 34a. Said phase difference is used to decide the shape of rotational movements and the level of sensitivity regarding changes in the rotational movement frequency with respect to the angular velocity.

AGC circuit 39 oscillates at fixed voltage E_s that is decided by reference voltage supply unit 42. An AC voltage from AGC circuit 39 is sent through rectifier 40, converted into DC voltage E_v , and compared with reference voltage E_s at integrator 41; whereby, the oscillation by AGC 39 is increased if DC voltage E_v is low, and the oscillation by AGC circuit 39 is reduced as DC voltage E_v becomes higher, so that the oscillation by AGC circuit 39 can be kept constant after all.

The AC voltage from AGC circuit 39 is combined with DC voltage E_b from DC power supply 44 and supplied to driving electrode 34a. DC voltage E_b is set in such a manner that it changes only in the positive voltage region when combined with the AC voltage. An AC voltage, that is obtained by shifting the phase for roughly 90° at phase shifter 43 and adding a DC voltage from DC power supply 44 to it, is supplied to the other driving electrode 34b. Whether vibrator 20 wobbles in the clockwise (will be referred to as CW, hereinafter) or counterclockwise (will be referred to as CCW, hereinafter) is decided depending on whether the 90° phase shifting is set forward or backward.

On the other hand, the AC voltage from AGC circuit 39 is supplied also to phase difference detection circuit 46 that constitutes an arithmetic operation part for computing the level and the direction of angular velocity Ω that is applied to vibrator 20. Phase difference detection circuit 46 detects the phase difference between a signal from reference frequency generation means 45, such as a reference vibrator that generates a fixed frequency irrespective of angular velocity Ω , and a signal from AGC circuit 39 at frequency ω_0 that corresponds to the frequency of the wobbling when angular velocity Ω of vibrator 20 is zero. Because said phase output becomes discontinuous at every 360° , and the sensitivity of the vibrator never reaches the logical sensitivity of 1, which will be described in detail below, computer 47 that corrects them and displays rotating angle $\overline{\theta}$.

Principles of the operations of the device configure in said manner will be explained next. Figure 3 shows a model in which vibrator 20 is simplified. Because vibrator 20 is adjusted in such a manner that the characteristic bending frequencies in all directions becomes the same, spring constant k , mass M , and the frequency of the rotational movements can be described using a system that operates at the same frequency as characteristic bending frequency ω_0 of vibrator 20 as shown in Figure 3. Here, assuming that rotational movements are circular in shape, mass M moves on a circular orbit with the radius of r and the center at point O . At this time, because the centrifugal force and the centripetal force generated by spring k almost balance out,

$$M r \omega_0^2 = r k \quad (2)$$

comes into effect. Here, angular frequency ω_0 of the vibrations matches the characteristic bending frequency of the vibrator, so it can be given by

$$\omega_0 = \sqrt{k/M} \quad (3)$$

Next, a case in which angular velocity Ω is applied around axis Z , that is formed at the right angle with respect to the circular orbit of mass M that runs through point O , in the system shown in Figure 3

will be considered. When angular velocity ω of mass M, drifting velocity v of mass M, and the centripetal force that are observed in the system rotating at angular velocity Ω are balanced out,

$$rk = Mr\omega^2 + Mr\Omega^2 + 2Mv\Omega \quad (4)$$

comes into effect. Here, while paying attention to

$$v = r\Omega,$$

when Formula (2) and Formula (4) are compared,

$$Mr\omega_0^2 = Mr(\omega + \Omega)^2 \quad (5)$$

or

$$\Omega + \omega_0 = \omega \quad (6)$$

results.

Therefore, when a deviation from rotational movement frequency ω is observed with reference to the same frequency as ω_0 , angular velocity Ω acted upon vibrator 20 can be found. Here, the rotational movement corresponds to the wobbling of vibrator 20.

In addition, its operations as an integrating gyro can be obtained easily by integrating Formula (6) with respect to time t . That is, assuming that the rotational angle of vibrator 20 is denoted as $\bar{\varphi}$,

$$\begin{aligned} \bar{\varphi} &= \int (\omega_0 - \omega) dt \\ &= \int (\omega_0 - \omega) dt \end{aligned} \quad (7)$$

comes into effect. That is, when reference frequency ω_0 and rotational movement frequency ω of reference frequency generation means 45 are supplied to phase difference detection circuit 46 to detect the deviation, although the value indicated by phase difference detection circuit 46 when angular velocity Ω becomes zero is fixed and does not change, the value indicated changes when angular velocity Ω is applied, so that the phase changes to the extent of rotational angle $\bar{\varphi}$.

Figure 4 shows an example when the angular velocity is measured using the vibration type angular velocity meter explained in the aforementioned application example. The vertical axis indicates phase difference (unit is $^{\circ}$) as indicated by phase difference detection circuit 46, and the horizontal axis represents a time axis. Because the wobbling frequency of vibrator 20 is 348.881 (Hz), reference frequency ω_0 is also 348.881 (Hz). Rotational angle $\bar{\varphi}$ of vibrator 20 is added at every $30 \pm 2^{\circ}$, and its angular velocity is 5 ($^{\circ}$ /sec.). At this time, the phase difference output is 0.98 time of rotational angle $\bar{\varphi}$.

As shown in Formula (6), the reasons as to why the sensitivity never become 1.00 time is that the orbit of mass M is not completely round, and the characteristic frequencies of the 2 characteristic bending modes of the vibrator do not match completely.

Figure 5 is a perspective view showing the configuration of another application example of the present invention, wherein a single body of vibrator is shown.

Mass member 21 is fixed to case 23 via supporting sections 22a and 22b that are arranged on a straight line. Mass member 21 is in the shape of a cylinder with a large diameter; and supporting sections 22a and 22b are formed into cylinders with a small diameter, and their center lines are aligned with each other. Case 23 is equipped with fixation parts 23a and 23b for securing supporting sections 22a and 22b and wall bodies 23c and 23d for supporting fixation parts 23a and 23b. Because wall bodies 23c and 23d are configured sufficiently larger than the cross-sectional areas supporting sections 22a and 22b, they are highly rigid.

Operations of the device configured in said manner will be explained next. The vibrator shown in Figure 1 (a) had a problem that, because the weight of mass member 21 acted upon supporting section 22 changed depending on postures of vibrator 20, the characteristic bending frequency of the vibrator was changed as the axial force of supporting section 22 changed. (While the changes in the characteristic frequency attributable to this factor is 1 ppm or less, for example, because the lower limit

of the angular velocity to be detected of the characteristic frequency of approximately 350 (Hz) is 0.01 (/sec.), the frequency needs to have the stability level of 0.08 ppm.)

In the case of the vibrator pertaining to Figure 5, because mass 21 is supported using 2 supporting sections 22a and 22b, the axial force acted upon supporting sections 22a and 22b never changes regardless of the postures of the vibrator, so that the characteristic bending frequency of the vibrator never changes.

A configuration in which supporting sections 22a and 22b are formed into the shape of a thin line, and mass member 21 is supported while a tension is applied to them may be adopted also. The point that the tension applied to supporting sections 22a and 22b remains constant regardless of the postures of the vibrator is no different from the vibrator shown in Figure 5.

Furthermore, the first invention is not restricted to the aforementioned application example; that is, although a case involving a round orbit for the wobbling movements was shown, an oval shape may be used. In addition, although the 2 characteristic bending frequencies of vibrator 2 matched perfectly, it is also feasible that $1/Q$ (Q is a quantity indicating the level of resonance of the vibrator system) of characteristic bending frequency ω_0 of said vibrator may be set to $\Delta\omega$, and the difference between the 2 characteristic bending frequencies is set within several times of $\Delta\omega$. The reason is that the vibrator can wobble at a sufficient amplitude even though the 2 characteristic bending frequencies may not match perfectly.

In addition, although the excitation means was driven electrostatically in the application example, the vibrator may be made of a magnetic material and driven electromagnetically, and a piezoelectric substance may be adhered to the vibrator so as to excite the vibrator.

In addition, although the frequency detection means detected the vibrations of the vibrator based on changes in the capacitance in the application example, the vibrator may be made of a magnetic body so as to utilize inductance to this end, or some other displacement detection means may be utilized. In

addition, the rotational movements of the vibrator may be detected by detecting the stress generated at the supporting section of the vibrator.

In addition, although the arithmetic operation part utilizes the same reference frequency as that obtained when the angular velocity is zero in order to detect changes in the rotational movement frequency, a highly stable reference clock with a high frequency may be utilized to detect changes in the rotational movement frequency.

Figure 6 and Figure 7 are perspective views showing configurations of application examples of the second invention, wherein a single body of vibrator is shown.

In Figure 6, 2 units of the vibrator pertaining to Figure 1 (a) are provided on case 23 on straight line Z. Mass member 21a provided at one end rotates CW, and the other mass member 21b rotates CCW.

In Figure 7, 2 units of the vibrator pertaining to Figure 1 (a) are provided on case 23 around the centers of parallel straight lines Z₁ and Z₂. Mass member 21a provided at one side rotates CW, and the other mass member 21b rotates CCW.

Operating principles of the devices configured in said manners will be explained next. Assuming that angular velocity Ω is CW, Formula (6) can be expressed as

$$\Omega_{CW} = \omega_{CCW} - \omega_{CW} \quad (8)$$

for one of the vibrators, and it can be expressed as

$$\Omega_{CW} = -(\omega_{CCW} - \omega_{CCW}) \quad (9)$$

for the other. Therefore, when they are used differentially, changes in the rotational movement frequencies with respect to angular velocities Ω of the vibrators, that is their sensitivities, can be doubled, and that changes in characteristic bending frequencies ω_0 attributable to posture errors and changes in temperature can be erased effectively.

Here, one of the vibrators pertaining to Figure 6 and Figure 7 may be engaged in linear bending vibrations so as to obtain reference frequency ω_0 while the other vibrator is engaged in rotational movements so as to detect angular velocity Ω .

Effects of the invention

As described above, the first invention has the following characteristics. First, because the case and the supporting section can be formed as a single structure, the structure of the vibrator can be simplified. In addition, because the output is the frequency, it can be digitally processed easily and incorporated into a computer easily.

With the second invention, because changes in the characteristic bending frequencies attributable to posture errors and changes in temperature can be erased effectively, a high-precision vibration type angular velocity meter can be realized.

Brief description of the figures

Figure 1 are perspective views showing the configuration of the cardinal part of an application example of the first invention; wherein, (a) shows a single body of vibrator, and (b) shows the overall view except for an arithmetic operation part. Figure 2 is a block diagram showing configurations of an excitation means and a frequency detection means. Figure 3 shows a model for explaining the operating principles. Figure 4 shows an example of measured angular velocity. Figure 5 shows another application example of the first invention. Figure 6 and Figure 7 are perspective views showing configurations of application examples of the second invention. Figure 8 is a diagram showing a conventional device configuration.

20 ... vibrator; 21 ... mass; 22 ... supporting section; 23 ... case; 31 ... electrode support; 34a, 34b ... driving electrode; 35a ... detection electrode; 36 ... capacitance detection circuit; 45 ... reference frequency; 46 ... phase difference detection circuit.

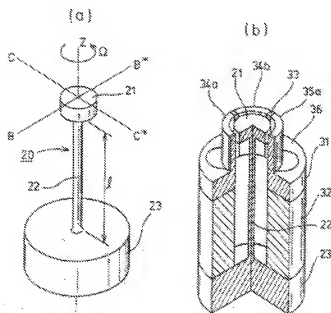


Figure 1

Key: 20 vibrator
 21 mass member
 22 supporting section
 23 case
 31 electrode support
 32 spacer
 33 counter surface
 34a, 34b driving electrode

- 35a detection electrode
36 outer cylindrical surface

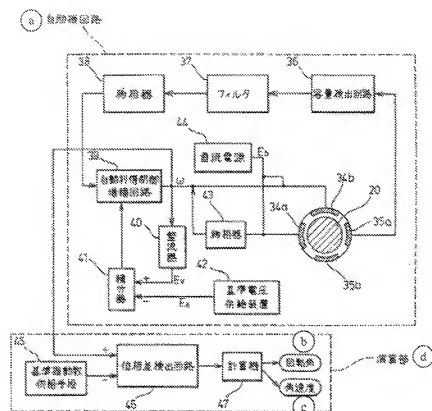


Figure 2

- Key: a self-excitation circuit
b rotational angle
c angular velocity
d arithmetic operation part
36 capacitance detection circuit
37 filter
38, 43 phase shifter

- 39 automatic gain control amplification circuit
- 40 rectifier
- 41 integrator
- 42 reference voltage supply unit
- 44 DC power supply
- 45 reference frequency supply [sic.; generation] means
- 46 phase difference detection circuit
- 47 computer

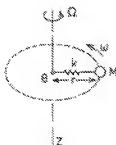


Figure 3

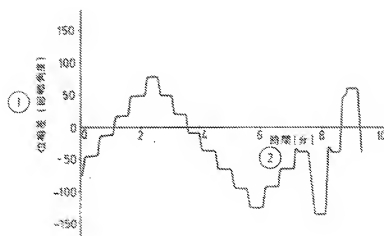


Figure 4

Key: 1 phase difference

2 time (min.)

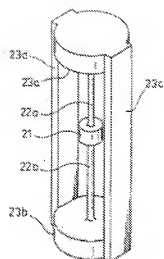


Figure 5

Key: 21 mass member

22a, 22b supporting section

23 case

23a, 23b fixation part

23c, 23d wall body

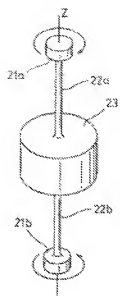


Figure 6

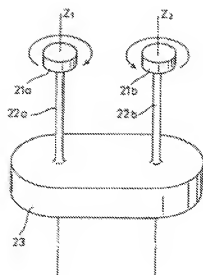


Figure 7

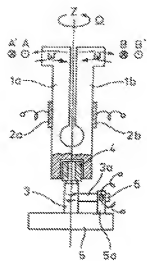


Figure 8